ABSTRACT

This study concerns some of the hydrological properties of the Hillsborough, Alafia, Little Manatee, and Manatee Rivers, which flow into Tampa Bay, Florida. Temperature, salinity, total phosphate-phosphorus, inorganic phosphate-phosphorus, nitrate-nitrite nitrogen, and copper content were recorded during a 15-month period. The observed variations are discussed in terms of differences in precipitation, river discharge, and general geological features of the area.

HYDROLOGICAL CHARACTERISTICS OF TAMPA BAY TRIBUTARIES

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This investigation is part of a study of Tampa Bay and adjacent neritic waters in connection with an effort to control the Florida red-tide menace. The Florida red tide is a natural fish-killing phenomenon in the waters along southwest Florida coast and is always associated with discolored water containing dense populations of *Gymnodinium breve*, a naked dinoflagellate. The primary objective was the collection of sufficient data to observe the natural levels and seasonal fluctuations of salinity, total phosphorus, inorganic phosphate, nitrate-nitrite nitrogen, and total dissolved copper in the Hillsborough, Alafia, Little Manatee, and Manatee Rivers which flow into Tampa Bay. Copper was included in this hydrological survey because of its high toxicity to laboratory cultures of *Gymnodinium breve*. Thus, copper was of particular interest as a possible limiting factor in the growth of *G. breve* in its natural surroundings. A secondary objective was to observe the influences of precipitation and the geological formations underlying the area upon the chemical composition of these rivers.

The chemical composition of the rivers has an important bearing on general problems of coastal oceanography (Ketchum, Redfield, and Ayers, 1951). Furthermore, it is essential that the chemical composition of the river waters be known for proper evaluation of the relative importance of the Tampa Bay area to red-tide research and other estuarine studies (Rochford, 1951; Spencer, 1956; and Manaché, 1958). Although the chemical composition of some Florida rivers has been studied previously by the U.S. Fish and Wildlife Service (Graham, Amison, and Marvin, 1954; Finucane and Dragovich, 1959; Dragovich and others, 1961); Geological Survey, Branch of Surface Waters, University of Florida (Specht, 1950); and by the Florida Geological Survey (Odum, 1953), little hydrological information has been gathered for the rivers flowing into Tampa Bay.

The authors are indebted to William B. Wilson for numerous valuable suggestions during this study. John A. Kelly, Jr., and John H. Finucane provided technical assistance.

MATERIALS AND METHODS

From October 1, 1958, through December 31, 1959, monthly collections of surface and bottom waters were made at eight stations (fig. 1). Samples for all analyses were taken with a weighted polyethylene container. Samples for total phosphate-phosphorus, inorganic phosphate-phosphorus, and nitrate-nitrite nitrogen were immediately transferred from the containers into 200-mm. culture vials which were capped with polyethylene-lined screw caps and quickly frozen. Samples for the determination of copper and salinity were transferred into 250-ml. glass-stoppered bottles, and those for salinity into 4-oz. prescription bottles. All containers used for sampling were chemically cleaned prior to use.

The following methods of analysis were employed:

Water temperature: Centigrade thermometer graduated in tenths of a degree.

Salinity: Mohr-Knudsen method (Knudsen, 1901).

Total phosphate-phosphorus: Harvey (1948) method.

Inorganic phosphate-phosphorus: Robinson and Thompson (1948) method.

Nitrate-nitrite nitrogen: Zwicker and Robinson (1944) method as modified by Marvin (1955).

Copper: Hoste, Eeckhout, and Gillis (1953) method.

Samples taken for copper analyses were filtered. Samples collected for phosphorus and nitrogen determinations were not filtered.

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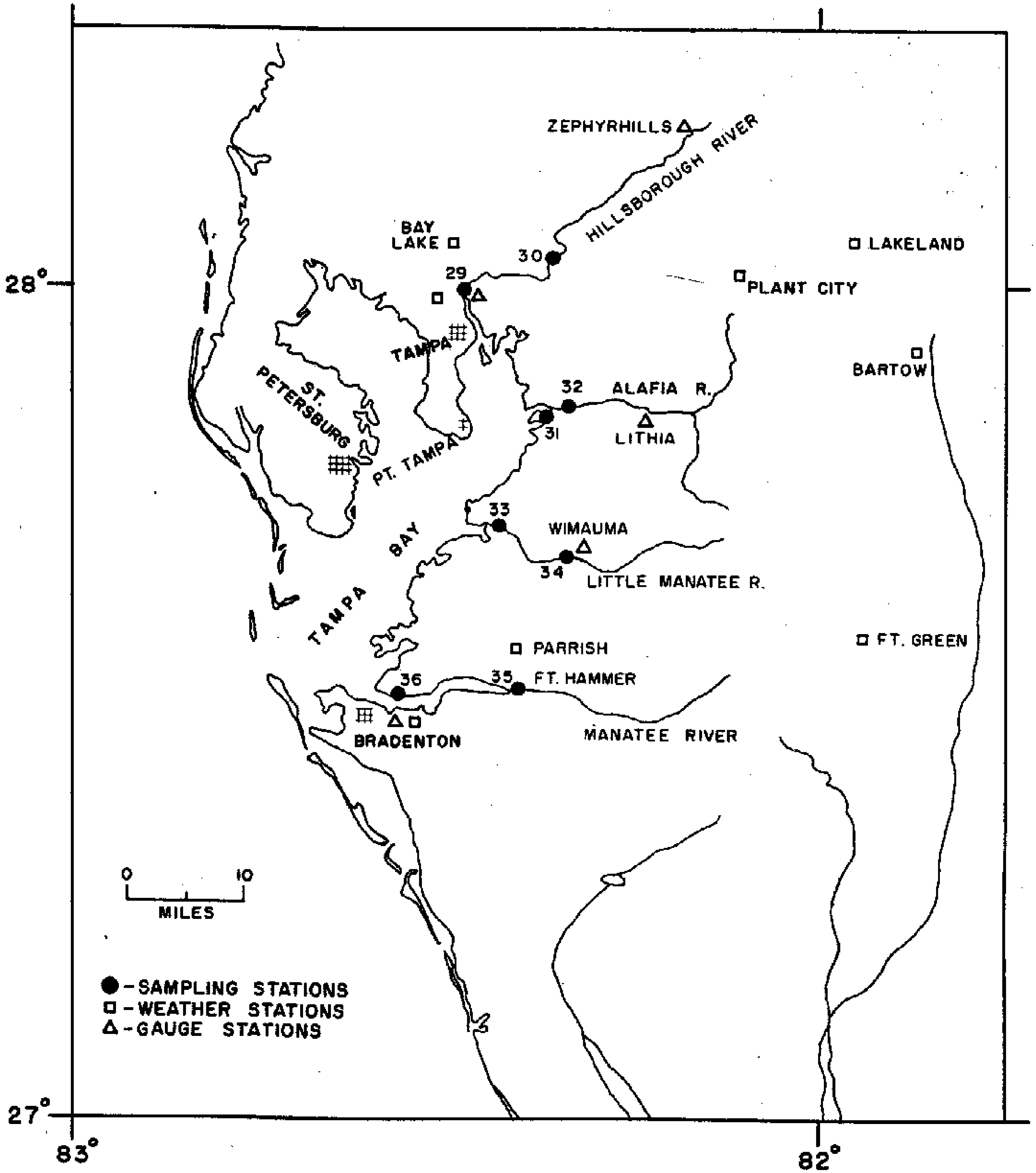

FIGURE 1.—Tampa Bay area showing rivers and sampling stations.

GENERAL DESCRIPTION OF THE AREA

The Hillsborough, Alafia, Little Manatee, and Manatee Rivers are relatively small and short, with sources less than 70 miles inland (fig. 1). These rivers are the main arteries of the Tampa Bay drainage basin, and all four river mouths are subject to tidal action. The mean range of tide is 1.9 feet at the lower end of Tampa Bay, 2 feet at Port Tampa, and 2.2 feet at Tampa. The extreme ranges at Port Tampa and at Tampa are 2.5 and 2.9 feet, respectively. Strong northerly winds lower the water level about 2 feet while strong southwesterly winds raise the water level about 1.5 feet.

Five gaging stations (fig. 1) are maintained in the rivers by the U.S. Geological Survey, Branch of Surface Waters, for the purpose of obtaining river discharge data.

Outstanding geological characteristics of the area are large phosphorus and limestone deposits. The major deposits containing phosphate are the Hawthorn (Miocene), Alachua (Pliocene), and Bone Valley (Pliocene) formations (fig. 2). Although the soils are high in lime and phosphorus, they are poor in copper, zinc, and manganese (Fuestel and Byers, 1933). The copper level has been supplemented in recent years in the citrus and truck farming areas by the addition of fertilizers of high copper content. Patches of peat and muck soils are scattered throughout the Tampa Bay drainage basin, although not to the extent observed in the Everglades. The detailed geology of the investigation area has been discussed by Cooke (1945).

The rainy season in the Tampa Bay area usually extends from June to October, and the streams reach seasonal high stages during late summer and early fall. The mean annual precipitation compiled from five centers (Bartow, Bradenton, Lakeland, Plant City, and Tampa) for the past 29 years (1931–59) is 53.5 inches.

The prevailing winds are easterly. The maximum wind velocity in the past 57 years was 75 miles per hour, while the mean velocity was 8.4 miles per hour. The Tampa Bay area has subtropical temperatures, generally with maxima in August and minima in January.

RESULTS

The water temperature ranged from 15.0° to 30.5° C. during this investigation. The seasonal decline in temperature in all rivers began in November during both observation years, reaching the seasonal minimum in December, which was followed by a sharp rise in January (figs. 3, 4, 5, and 6). From January through March, the temperature increased slightly in the Little Manatee River. In the Hillsborough, Manatee, and Alafia Rivers, a slight increase was recorded from January through February, followed by a drop in March. From March to May, temperature increased sharply in all rivers and remained variably high from May to October.

The frequency distribution of the temperature differences between surface and bottom ranged from 0.0° C. to 0.5° C. in 83.3 percent of the samples; 0.6° C. to 1.0° C. in 10.9 percent of the samples; and 1.1° C. to 3.1° C. in 5.8 percent of the samples. This distribution indicates close similarity between the surface and bottom temperatures.

The maximum salinity, 24.83 ‰, was observed at the bottom of station 36 while a minimum of 0.04 ‰ was recorded at stations 34, 35, 30, 31, and 32 (figs. 3, 4, 5, and 6). The salinity values indicated that station 30, Hillsborough River, and station 34, Little Manatee River, possessed limnetic characteristics throughout the observation period. Their respective ranges were 0.04 ‰ to 0.32 ‰ and 0.04 ‰ to 0.48 ‰. At all remaining stations much greater variation in salinity was noted.

Total annual precipitation in the Tampa Bay area was 57.4 inches in 1958 and 82.1 inches in 1959. The precipitation regime for the Hillsborough and Alafia drainage areas differed from that of the Little Manatee and Manatee River areas, the latter having more rain during the summer months (figs. 3, 4, 5, and 6). The early onset of the rainy season in March was most pronounced in the Hillsborough and Alafia areas.

In the Hillsborough and Alafia River drainage areas, maximal discharges began in March and, with the exception of a decline in May, remained variably high through October for the Hillsborough, and through September for the Alafia

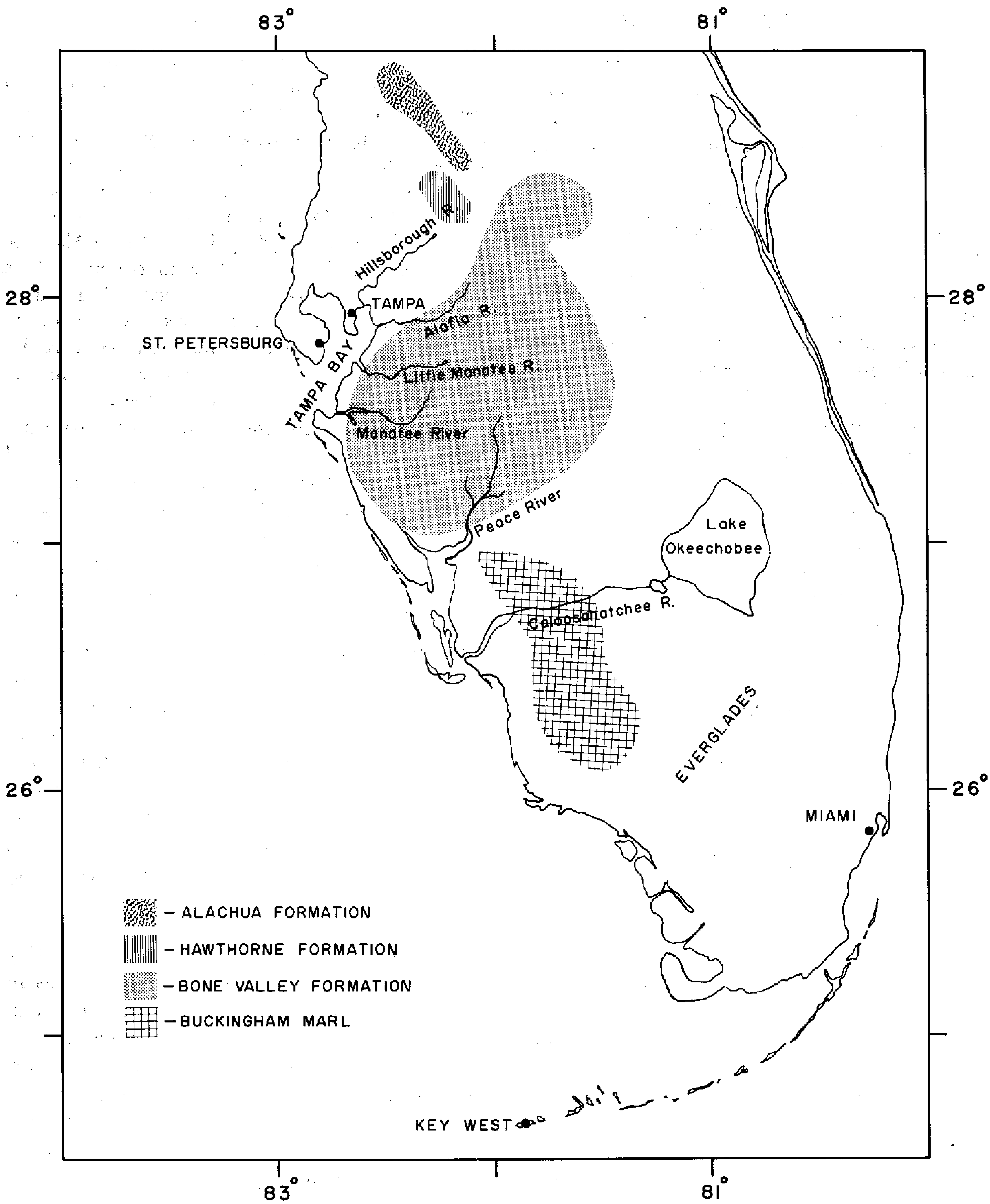

FIGURE 2.—Map of surface phosphate-bearing formations (after Cooke, 1945).

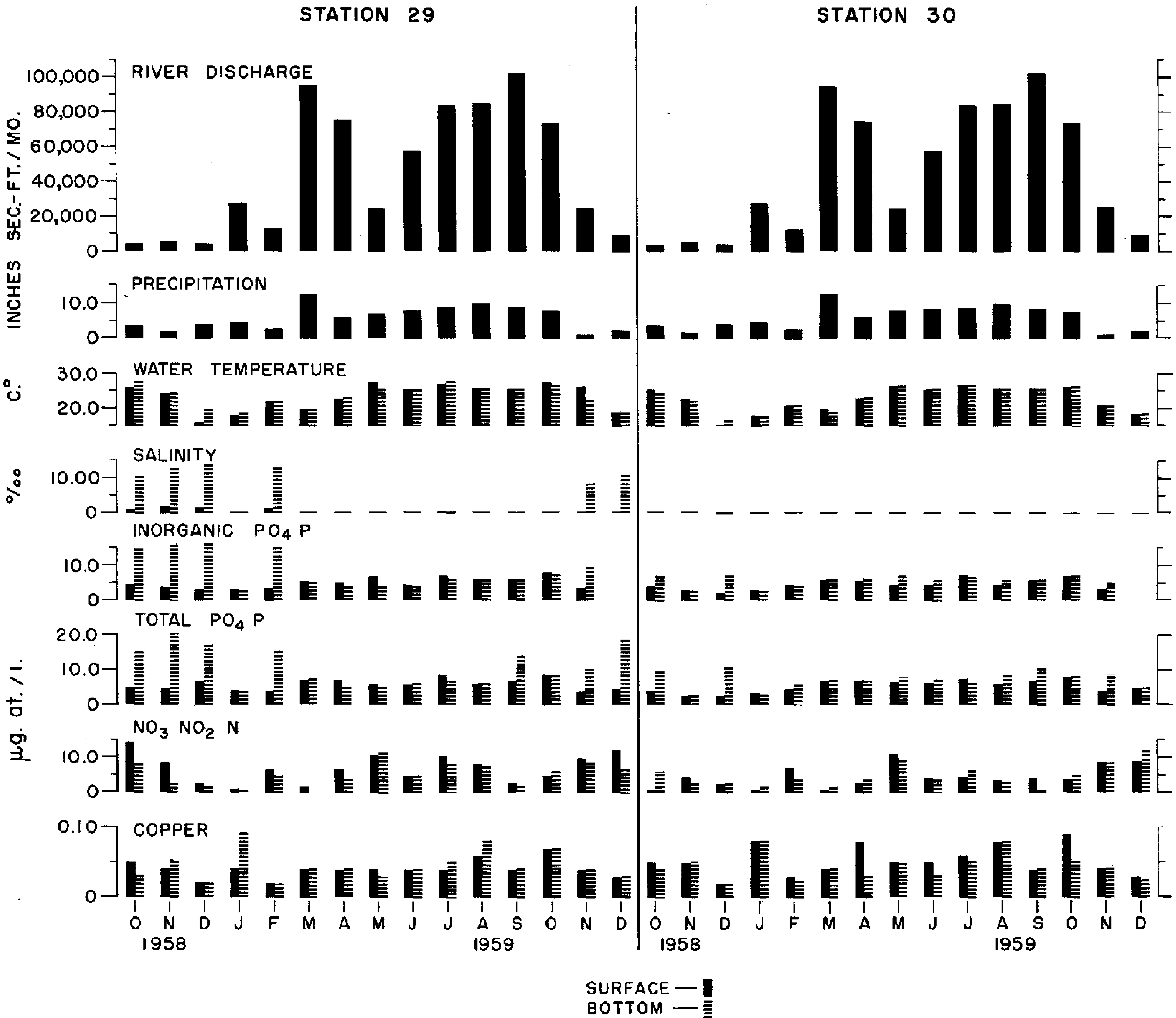

Figure 3.—River discharge, precipitation, and hydrological properties of Hillsborough River, Florida, October 1958–December 1959.

River. In the Little Manatee River the maximum discharges were from March through September. Data for October, November, and December 1959 are available only for the Hillsborough River. The river discharges were considerably higher in the Hillsborough and Alafia Rivers than in the Little Manatee and Manatee Rivers (figs. 3, 4, 5, and 6). The maximum discharge for the four rivers for the water year, beginning October 1958 and ending September 1959, was observed in the Hillsborough River (564,244 second-feet per day). The minimum discharge was recorded in the Manatee River (82,899 second-feet per day).

The concentrations of total phosphorus for all rivers varied from 2.5 µg.at./l., observed at the Hillsborough River at station 30, to 60.5 µg.at./l. recorded in the Alafia River at station 32.

The concentrations of total phosphorus in the Alafia River are extremely high in comparison to those in the other three rivers. The average total phosphorus value of 39.2 µg.at./l. for the Alafia River is 3.1 times that of the average value (12.6 µg.at./l.) observed in the next highest river, the Little Manatee. The monthly variations in phosphorus were similar at stations 31 and 32 which are 2.5 miles apart.

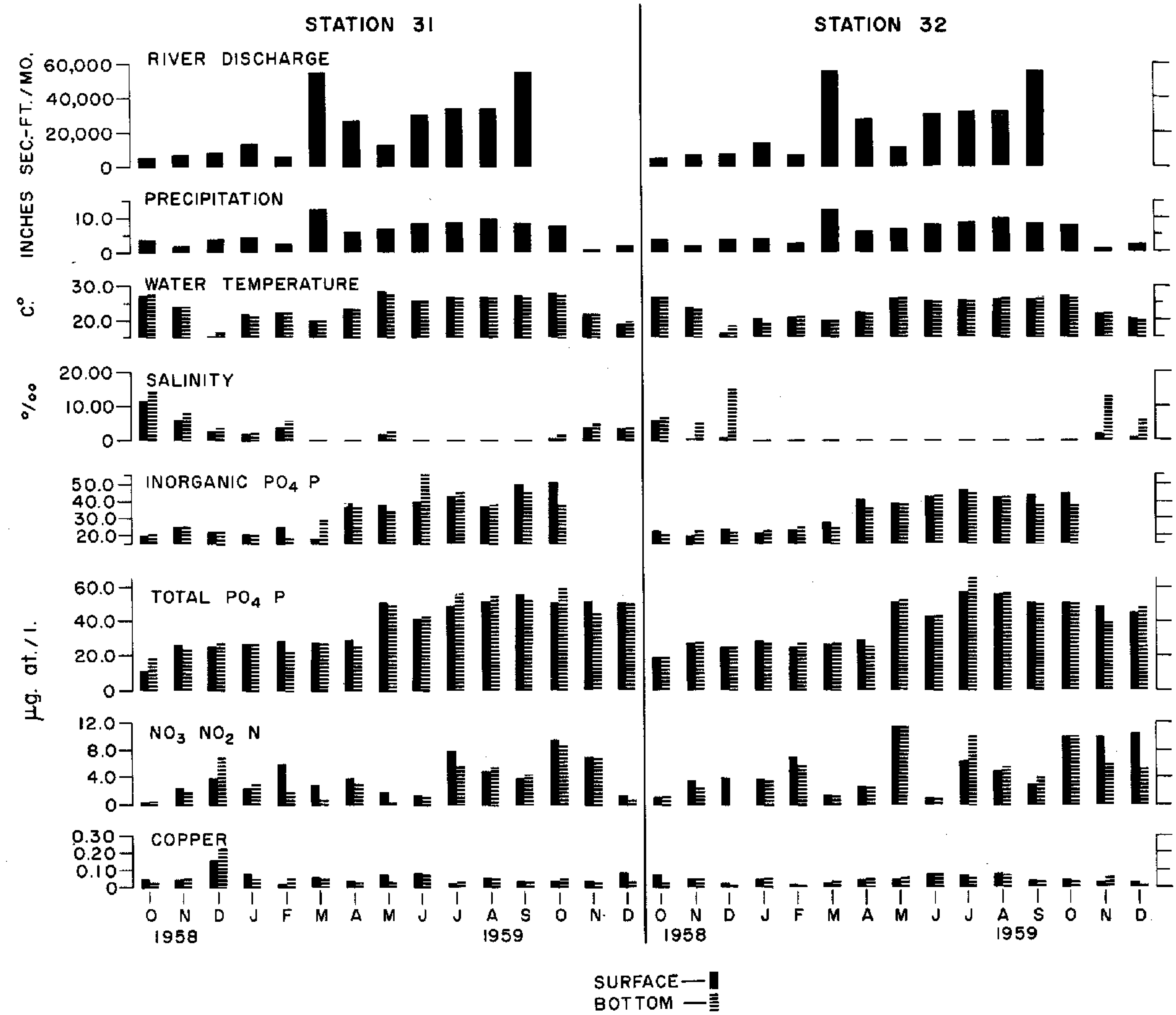

FIGURE 4.—River discharge, precipitation, and hydrological properties of Alafia River, Florida, October 1958–December 1959.

Concentrations of total phosphorus in the Little Manatee River were in turn higher than in the Manatee River, which showed higher concentrations downstream, with little difference between surface and bottom values (fig. 5).

The lowest concentrations of total phosphorus were observed in the Hillsborough River. In this river the vertical distribution of total phosphorus for the entire period showed higher values near the bottom whenever bottom salinity values were above normal (table 1). In March an increase in surface concentrations of total phosphorus and vertical homogeneity was evident. The surface and bottom total phosphorus concentrations remained variably high until the reappearance of stratified conditions in November. The distribution of total phosphorus at upstream station 30 was somewhat similar to that of station 29, but with greater vertical homogeneity (fig. 3).

The spatial and temporal distribution pattern of inorganic phosphate-phosphorus in the rivers was essentially the same as that of total phosphate-phosphorus (figs. 3, 4, 5, and 6). The mean inorganic phosphate values for the individual rivers represented 77 to 95 percent of the total. Organic phosphorus exceeded inorganic on only one occasion, at station 29 during September at the period of maximum discharges. Unusually high

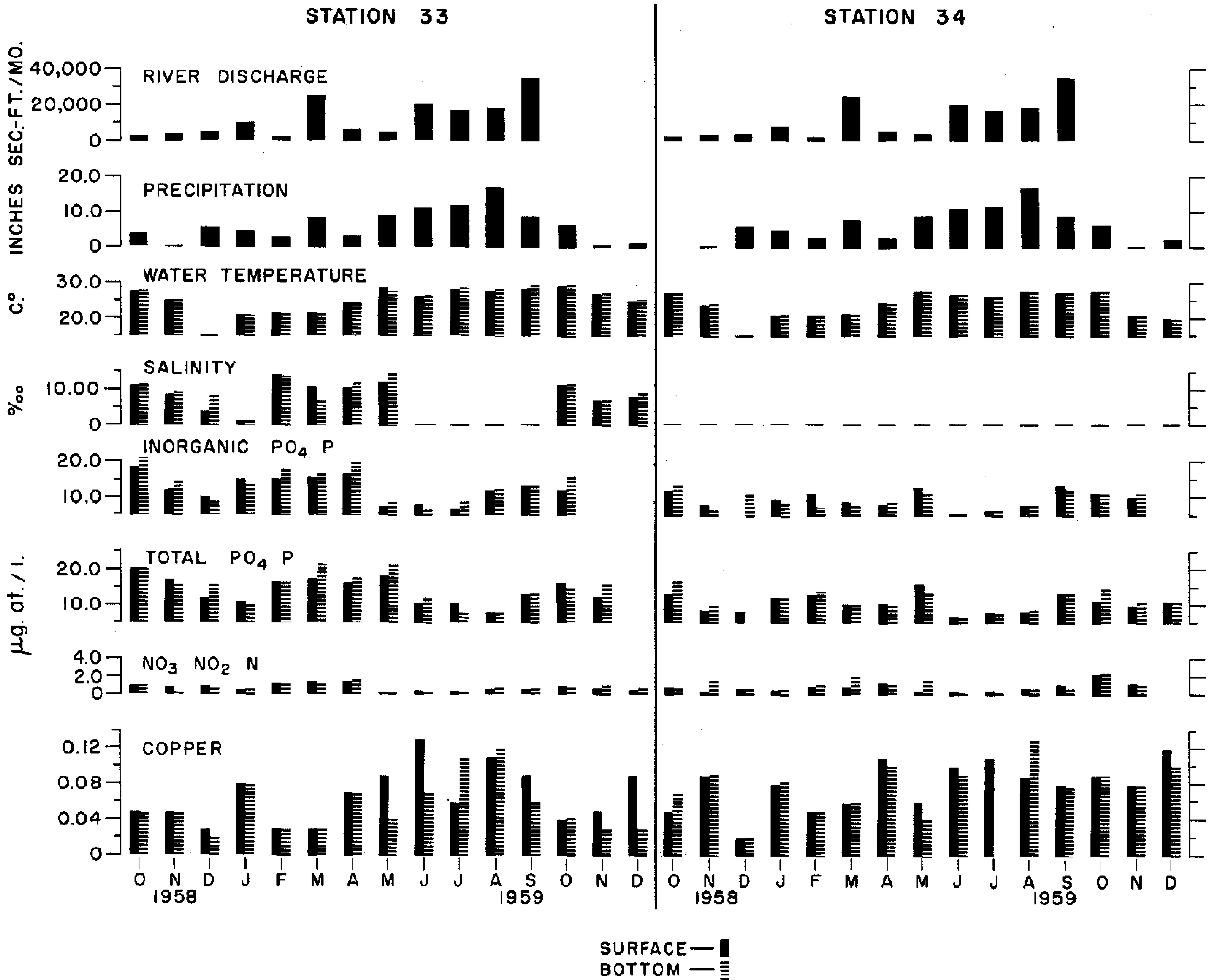

Figure 5.—River discharge, precipitation, and hydrological properties of Little Manatee River, Florida, October 1958–December 1959.

concentrations of organic phosphorus were observed in the Alafia River. High concentrations of inorganic phosphate-phosphorus in May were accompanied by high values of organic phosphorus (10.2–16.8 μg.at./l.). From May through October, with the exception of two values (0.0 and 0.2 μg.at./l.), the concentrations of organic phosphorus remained high.

Concentrations of nitrate-nitrite nitrogen in all rivers varied from 0.1 to 13.7 μg.at./l. Values for the Hillsborough and Alafia were 2 to 10 times higher than those for the Little Manatee and Manatee Rivers. The seasonal distribution of nitrate-nitrite nitrogen concentrations was very irregular at all stations (figs. 3, 4, 5, and 6). The highest concentrations of nitrate-nitrite nitrogen were recorded in the Hillsborough River, at station 29 (table 2). The Alafia and Little Manatee Rivers showed higher values at upstream than at downstream stations.

Concentrations of total dissolved copper in all rivers varied from 0.00 to 0.22 μg.at./l. The monthly copper values were very irregular at all stations. The Little Manatee River showed the highest average copper level for the investigation period (table 2). The highest values (0.22 and 0.16 μg.at./l.) were observed at station 31 in the Alafia River during December when copper values for five other stations were low. Except in the case of the Alafia River, slightly higher concentrations of copper were observed at the upstream stations (table 2).

TABLE 1.—*Total phosphorus and inorganic phosphate in Tampa Bay and tributaries, October 1958–December 1959*

[Units in µg.at./l.]

Location	Total PO_4 P			Inorganic PO_4 P		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Hillsborough River:						
Station 29:						
Surface	3.9	8.3	5.8	2.7	7.9	4.9
Bottom	3.4	18.6	10.3	2.6	16.6	8.3
Station 30:						
Surface	2.5	13.9	6.1	2.7	7.4	4.7
Bottom	2.5	10.4	7.1	2.5	7.2	5.7
Alafia River:						
Station 31:						
Surface	20.3	55.8	38.8	19.7	51.2	33.5
Bottom	18.1	58.1	39.2	19.7	55.8	32.3
Station 32:						
Surface	25.0	58.1	39.7	20.2	46.9	34.9
Bottom	24.1	60.5	39.1	21.4	44.8	32.2
Little Manatee River:						
Station 33:						
Surface	8.2	19.8	13.0	6.9	18.6	12.3
Bottom	7.9	21.0	14.9	6.3	20.1	13.0
Station 34:						
Surface	7.0	16.5	10.9	5.3	13.8	9.7
Bottom	6.7	16.8	11.4	5.5	13.7	9.2
Manatee River:						
Station 35:						
Surface	4.7	13.0	10.1	5.9	10.9	8.4
Bottom	8.1	13.2	10.3	6.0	13.0	8.6
Station 36:						
Surface	8.6	19.6	11.9	7.7	18.0	10.1
Bottom	8.8	18.4	11.8	8.1	15.5	10.3
Tampa Bay, off mouth of Little Manatee River:						
Station 3 (27°41.6′ N., 82°33.5′ W.):						
Surface	15.1	33.2	23.3	15.1	29.6	21.0
Bottom	15.9	25.6	19.2	13.1	22.9	17.6
Station 4 (27°41.3′ N., 82°32.9′ W.):						
Surface	16.6	27.1	22.1	14.5	25.8	20.2
Bottom	16.0	26.7	21.6	12.5	23.2	18.2

TABLE 2.—*Concentrations of nitrate-nitrite nitrogen and total dissolved copper in Tampa Bay tributaries, October 1958–December 1959*

[Units in µg.at./l.]

Location	NO_3-NO_2N			Cu		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Hillsborough River:						
Station 29:						
Surface	1.1	13.7	7.0	0.02	0.07	0.04
Bottom	0.8	11.2	5.2	.02	.09	.04
Station 30:						
Surface	.7	10.8	4.6	.02	.09	.05
Bottom	.9	12.2	4.7	.02	.08	.04
Alafia River:						
Station 31:						
Surface	.4	9.3	3.9	.02	.16	.06
Bottom	.4	8.8	3.6	.03	.22	.06
Station 32:						
Surface	1.0	11.3	5.5	.02	.08	.05
Bottom	0.7	11.2	5.1	.01	.08	.04
Little Manatee River:						
Station 33:						
Surface	.1	1.3	0.7	.03	.13	.07
Bottom	.1	1.6	0.8	.02	.12	.06
Station 34:						
Surface	.3	2.7	1.0	.02	.12	.08
Bottom	.3	2.6	1.2	.02	.13	.08
Manatee River:						
Station 35:						
Surface	.4	6.8	1.2	.02	.11	.06
Bottom	.3	2.2	0.9	.02	.15	.06
Station 36:						
Surface	.1	2.7	1.1	.00	.16	.05
Bottom	.2	3.6	1.3	.01	.13	.04

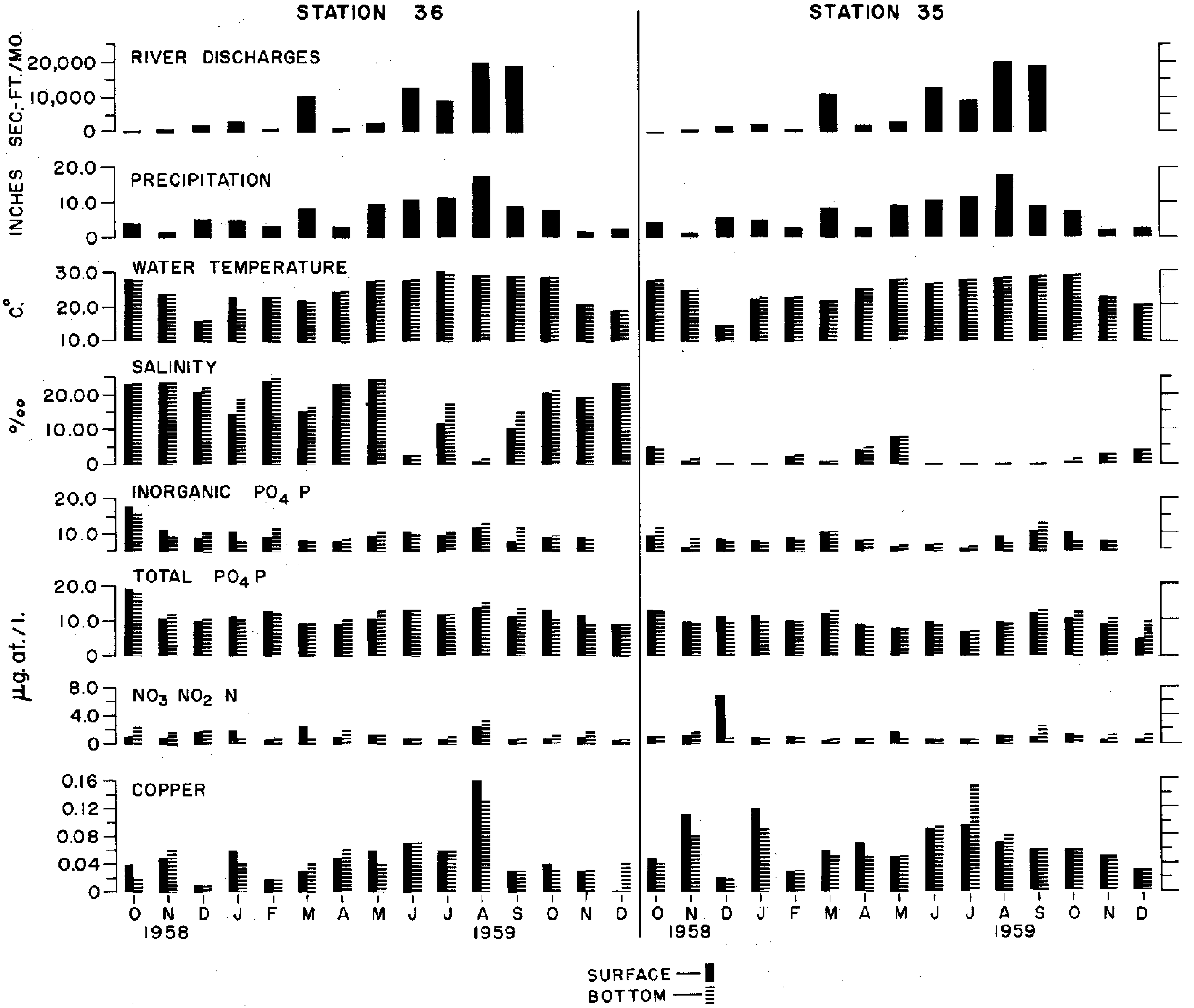

Figure 6.—River discharge, precipitation, and hydrological properties of Manatee River, Florida, October 1958–December 1959.

DISCUSSION

The annual temperature range of 15.0° to 30.5° C. observed for Tampa Bay tributaries is comparable to ranges of the shallow coastal subtropical waters at Naples, Florida (Dragovich, 1961), and to bay waters of Texas (Collier and Hedgpeth, 1950). Rapid changes in water temperature during the winter are of considerable significance to the resident biota. Sudden cold spells may result in fish mortalities (Springer and Woodburn, 1960) or influence spawning and migrations in estuaries (Collier and Hedgpeth, 1950).

In general there was a rather good relation between monthly precipitation and river discharges.

Only two river stations, 30 and 34, had fresh-water salinity values (<0.5 °/₀₀) throughout the entire period of investigation. At the remaining stations the salinity levels ranged from oligohaline (0.5 °/₀₀ to 5 °/₀₀) and mesohaline (5 °/₀₀ to 18 °/₀₀) to polyhaline (18 °/₀₀ to 30 °/₀₀). The influence of precipitation was obvious, particularly at stations 29, 31, 32, 33, and 35. The salinity distribution at these stations indicated an alternation between brackish- and fresh-water environments. This condition presents ecological barriers to some organisms from both marine and fresh-water ends of the estuary. In this regard *G. breve*, the Florida red-tide organism, was never found at stations 29, 31, 33, and 36 even when a red-tide outbreak occurred in lower Tampa Bay and offshore areas. In view of the *G. breve* salinity tolerance findings of Aldrich and Wilson (1960), it seems probable that even the maximum salinity (24.83 ‰) noted at these stations was too low to permit growth of this organism. Low concentrations of *G. breve* (up to 13 per ml.) were observed in samples taken near Bradenton during the red-tide outbreak in 1957. Salinity values for these positive samples were somewhat higher: 25.73 ‰ to 29.27 ‰ (Dragovich and others, 1961).

The distribution of total and inorganic phosphate-phosphorus in the rivers demonstrates the influence of underlying phosphatic formations. Higher concentrations of total and inorganic phosphate were recorded in the Alafia, Little Manatee, and Manatee Rivers which flow through a phosphatic district than in the Hillsborough River which has less contact with natural phosphate deposits.

In contrast to the scarcity of phosphorus in the oceans (Harvey, 1957; Sverdrup, Johnson, and Fleming, 1946), an abundance of this important nutrient element was found in all rivers flowing into Tampa Bay. On the basis of in vitro work (Ketchum, 1939), the concentrations observed represent a more than adequate supply for phytoplankton growth. A sizable contribution of total phosphorus to the waters of Tampa Bay is evident from data presented in table 1. A parallel investigation in Tampa Bay (Dragovich and others, 1961) has shown that upper Tampa Bay waters are richer in phosphorus than all Bay tributaries with the exception of the Alafia River (table 1). The Alafia River contributes the largest quantities of phosphorus to Tampa Bay. Graham, Amison, and Marvin (1954), in their phosphorus studies of the Caloosahatchee and Peace Rivers, observed a high average concentration (12.0 μg.at./l.) of total phosphorus in the Peace River. This value was less than one-third that of the Alafia. Average concentrations of inorganic (1.21 μg.at./l.) and total phosphorus (2.63 μg.at./l.) in the Caloosahatchee River are very low if compared with the corresponding values for any of the rivers flowing into Tampa Bay.

High concentrations of total phosphorus in the rivers were due largely to inorganic phosphate, which represented 77 to 95 percent of the total. Inorganic and total phosphorus were higher at the stations nearer the Bay than at the upstream stations, except in the Alafia River. From figure 7 it is apparent that the maximum concentrations of total phosphorus at station 29 were observed near the bottom and at highest salinities. The difference in total phosphorus values for the surface and bottom at station 33 appears to be insignificant. A phosphorus-salinity relation at stations 31 and 36 is not apparent. However, at station 31 phosphorus values at the few high-salinity levels noted were well below those observed at low salinities. The maximum total phosphorus values at station 36 (fig. 7) cannot be regarded as representative, for the samples were extremely rich in particulate matter.

Maximum concentrations of inorganic and total phosphorus in the Alafia River were recorded during the rainy season at the period of maximum discharges. In the Hillsborough River, where highest river discharges were recorded, a moderate surface increase in inorganic and total phosphorus was observed from March to September at both stations. This pattern was not evident in the Manatee River and the Little Manatee River data. High concentrations of organic phosphorus observed in the Alafia River from May to October may indicate increased biological activity.

In contrast to the high concentrations of phosphorus, the nitrate-nitrite nitrogen observed for these rivers can be considered moderate or low. The distribution of nitrate-nitrite nitrogen observations for all stations (fig. 8) clearly shows the existence of higher concentrations in the Hillsborough and Alafia Rivers than in the Little Manatee and Manatee Rivers. This pattern is similar to that of river discharges. The concentrations of nitrate-nitrite nitrogen in the Hillsborough and Alafia Rivers are comparable to the surface concentrations in certain marine areas such as the Gulf of Maine (Rakestraw, 1936), English Channel (Cooper, 1937), or Arabian Sea off Calcutta (Panikkar and Jayaraman, 1953), while the concentrations in the Little Manatee and Manatee Rivers, if compared to the same areas, are extremely poor. The seasonal distribution of nitrate-nitrite nitrogen and its short-term response to river discharge variation were very irregular.

The mean concentrations of nitrate-nitrite nitrogen in the Hillsborough and Alafia Rivers are

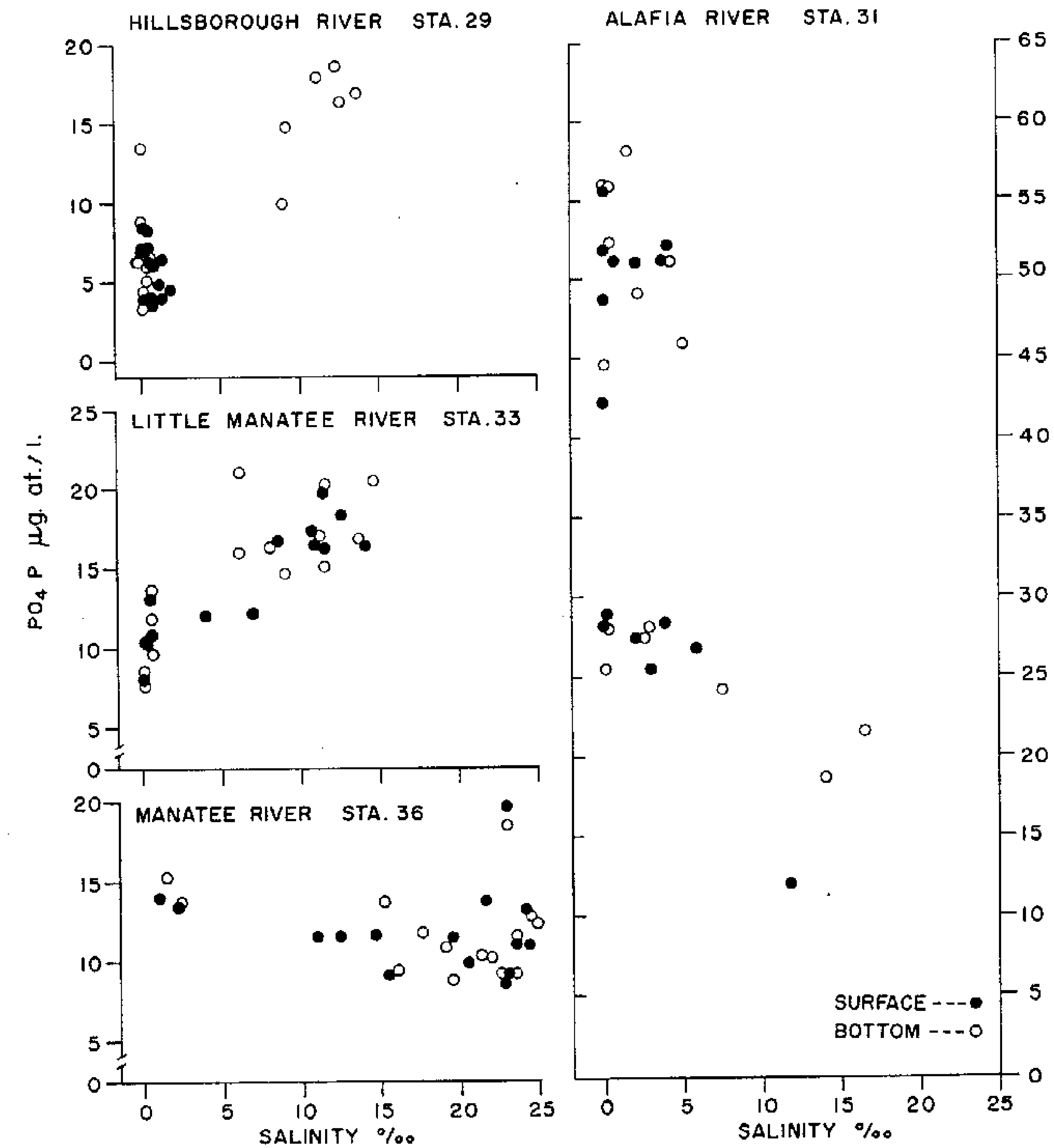

FIGURE 7.—Phosphorus-salinity relation of Tampa Bay tributaries, October 1958–December 1959.

comparable to the mean value (4.7 μg.at./l.) for the Peace River and higher than that for the Caloosahatchee River (2.2 μg.at./l.) (Finucane and Dragovich, 1959). The Little Manatee and Manatee Rivers were even poorer than the Caloosahatchee River in nitrate-nitrite nitrogen. None of these Florida rivers approach the Mississippi River level (14.6 μg.at./l.) for this nutrient (Riley, 1937).

The present data for the rivers, together with parallel observations in Tampa Bay (Dragovich and others, 1961), suggest that the rivers do not enrich the waters of Tampa Bay to an appreciable degree with nitrate-nitrite nitrogen. Dragovich

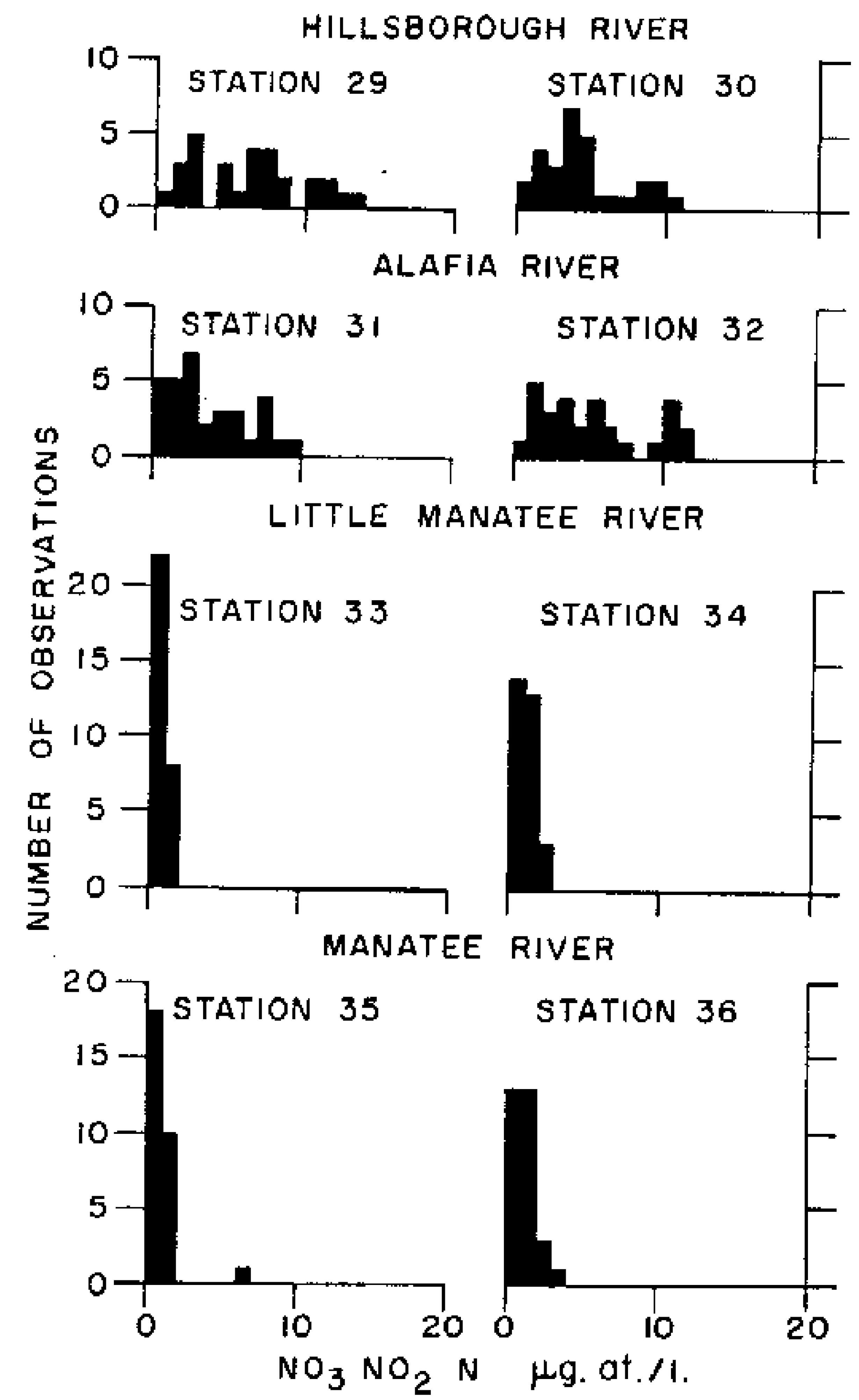

FIGURE 8.—Distribution of nitrate-nitrite nitrogen for rivers flowing into Tampa Bay, October 1958–December 1959.

and others (1961) have shown an extremely low mean concentration of nitrate-nitrite nitrogen (0.3 μg.at./l.) for Tampa Bay during the period of the present study.

Higher nitrate-nitrite concentrations near the Bay than at the upstream stations of the Hillsborough River suggested that enrichment of this river might be from waters somewhere between stations 29 and 30. To check this possibility our observations were extended in October, November, and December 1959 to Sulphur Springs, an underground tributary, located between stations 29 and 30. Nitrate-nitrite nitrogen concentrations in these springs varied from 11.1 to 17.0 μg.at./l., with a mean value of 13.5 μg.at./l. which is comparable to the maximum value observed at station 29. These results suggest that enrichment in nitrate-nitrites at station 29 is partially attributable to these springs.

The copper concentrations in Tampa Bay and adjacent neritic waters for the period from October 1958 through December 1959 varied from 0.00 to 0.10 μg.at./l. with an average of 0.03 μg.at./l. (Dragovich and others, 1961). Thus the mean copper concentration of Tampa Bay is about half of that observed in the rivers.

Copper is generally considered to be an essential constituent of protoplasm, especially in the synthesis of haemocyanin, haemoglobin, cytochrome *a*, and certain metalloflavoproteins (Mahler, 1956). Copper is taken up by phytoplankton (Atkins, 1953). The concentrations of copper in

tissues of certain soft marine invertebrates are about 5,000 times greater than the concentrations observed in the sea (Bieri and Krinsley, 1958; Krumholz and others, 1957). On the other hand, this element is selectively toxic to some organisms, including some algae, barnacles, and gastropods. Laboratory experiments demonstrated that the minimum dissolved copper lethal to *G. breve* in blooming proportions is about 0.5 μg.at./l. (Wilson).[1] Results of this investigation have shown that the average concentration of copper for all rivers combined is well below the toxic levels for *G. breve*. The frequency distribution of copper shows that in 75.6 percent of all observations the concentrations ranged from 0.03 to 0.08 μg.at./l.

The copper concentrations (0.04 μg.at./l.) tabulated by Chow and Thompson (1952) in the low-salinity waters off the mouth of the Mississippi River are comparable to the concentrations observed in the Hillsborough River but are below those observed in the other rivers. The copper levels in all four rivers were higher than those observed in the San Juan Channel, Washington (Chow and Thompson, 1954).

SUMMARY

The estuarine portions of the four main Tampa Bay tributaries can be characterized as subtropical areas subject to considerable variations in several ecologically important factors. These waters seem to be strongly influenced by local precipitation and natural phosphate deposits.

Temperature, salinity, total and inorganic phosphate-phosphorus, nitrate-nitrite nitrogen, and copper were determined monthly for the four main Tampa Bay tributaries. The temperature variations were characterized by rapid changes during the winter and thermal homogeneity from May to October. Salinity was markedly reduced during months of heavy rainfall and river discharges. High phosphate levels were observed in all four rivers. Their drainage areas are rich in natural phosphatic deposits. Extremely high concentrations of phosphate-phosphorus observed in the Alafia River exceeded those in upper Tampa Bay. In the three remaining Tampa Bay tributaries, the concentrations of phosphate-phosphorus were lower than those observed in upper Tampa Bay. Higher concentrations of nitrate-nitrite nitrogen were noted in the Hillsborough and Alafia Rivers than in the Little Manatee and Manatee Rivers. The nitrate-nitrite nitrogen data indicate that rivers do not enrich the waters of Tampa Bay to an appreciable degree. Concentrations of copper averaged twice those observed in Tampa Bay.

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